Claims

What is claimed is:

[c1] An apparatus for measuring formation resistivity through a conductive pipe in a wellbore, comprising:

a sonde adapted to be moved through the wellbore;

a plurality of voltage measurement electrodes disposed on the sonde at spaced apart locations, the voltage electrodes adapted to make electrical contact with the pipe;

at least one current source electrode disposed on the sonde, the current source electrode adapted to make contact with the pipe; and

a digital voltage measuring circuit controllably coupled to selected ones of the voltage measurement electrodes.

[c2] The apparatus of claim 1 wherein the digital voltage measuring circuit comprises of at least a twenty four bit resolution analog to digital converter.

[c3] The apparatus of claim 2 wherein the analog to digital converter has a sampling rate of at least one thousand times a frequency of electrical current used to energize the at least one current source electrode.

[c4] The apparatus of claim 1 further comprising a digitally synthesized current source coupled to the at least one current source electrode.

[c5] The apparatus of claim 4 wherein the current source is adapted to generate switched direct current.

[c6] The apparatus of claim 4 wherein the current source is adapted to generate switched direct current having less than a one hundred percent duty cycle.

[c7] The apparatus of claim 4 wherein the current source is adapted to generate alternating current having a selected frequency and waveform.

[c8] The apparatus of claim 4 wherein the current source is adapted to generate a pseudo random binary sequence.

[c9] The apparatus of claim 1 further comprising at least one focusing current source controllable to maintain a selected voltage drop across a pair of reference potential electrodes, the focusing current source electrically coupled to selected electrodes on the sonde.

[c10] The apparatus of claim 1 wherein the digital voltage measuring circuit is adapted to determine a direct current bias extant on the voltage measurement electrodes by operating substantially continuously.

[c11] The apparatus of claim 1 further comprising:

at least one focusing current source controllable to maintain a selected voltage drop across a pair of reference potential electrodes, the focusing current source electrically coupled to selected electrodes on the sonde; and

a switch adapted to selectively connect selected ones of the electrodes to the focusing current source and to the digital voltage measuring circuit.

[c12] The apparatus of claim 11 further comprising a processor coupled to the switch, the processor adapted to operate the switch to select which of the electrodes is coupled to the digital voltage measuring circuit, which of the electrodes is coupled to a measuring current source and which of the electrodes is coupled to the focusing current source.

[c13] The apparatus of claim 12 wherein the processor is adapted to select respective electrode connections by interpretation of command signals transmitted to the apparatus from a control unit disposed at the Earth's surface.

[c14] The apparatus of claim 12 wherein the processor is adapted to select respective electrode connections based on measured voltage drops across at least two of the electrodes.

[c15] The apparatus of claim 1 further comprising: a current return electrode coupled to the pipe proximate the Earth's surface and a current return electrode disposed proximate the

Earth's surface at a selected lateral distance from the current return electrode coupled to the pipe, and a switch to select a return path for measuring current from the current source electrode to the selected one of the electrode at coupled to the top of the pipe and the electrode disposed at the selected lateral distance from the pipe.

[c16] The apparatus of claim 1 further comprising a first switch operatively coupled between the plurality of voltage measurement electrodes, the current source electrode and the digital voltage measuring circuit, and a second switch operatively coupled between the plurality of voltage measurement electrodes, the current source electrode and a source of measuring current, the first and second switches operable to connect selected ones of the plurality of voltage measurement electrodes and the current source electrode between the digital voltage measuring circuit and the current source so as to make measurements of voltage drop representing at least one of selected lateral depths of investigation and selected axial resolution.

[c17] The apparatus of claim 16 further comprising a controller disposed proximate the sonde, the controller adapted to automatically operate the first and second switches.

[c18] The apparatus of claim 17 wherein the controller comprises programming for automatic operation of the first and second switches according to a predetermined sequence.

[c19] The apparatus of claim 17 wherein the controller is adapted to detect commands transmitted from the Earth's surface for reprogramming the operation of the first and second switches.

[c20] A method for measuring resistivity of Earth formations from within a conductive pipe inside a wellbore, comprising:

conducting an electrical current between a first selected position in the wellbore through the conductive pipe to a second position along the pipe near the Earth's surface;

digitally sampling a voltage drop measured between a third and fourth selected positions along the pipe between the first and second selected positions;

conducting an electrical current between the first selected position and a fifth selected position near the Earth's surface away from the pipe;

repeating the digitally sampling the voltage drop between the third and fourth position; and

determining resistivity of the Earth formation from the digital samples of voltage drop.

[c21] The method of claim 20 further comprising moving the first, the second and the third positions, and repeating both the digitally sampling and the repeated digitally sampling.

[c22] The method of claim 20 further comprising conducting a focusing current from a selected position along the pipe, the focusing current configured to constrain flow of current from the first position to the fifth position along substantially laterally outward paths from the wellbore in the lateral vicinity of the wellbore.

[c23] The method of claim 22 further comprising controlling a magnitude of the focusing current so that a voltage drop measured axially along the wellbore between selected positions remains substantially zero.

[c24] The method of claim 20 further comprising controlling a duty cycle of the current flowing from the wellbore to the second and to the fifth positions near the Earth's surface to correspond to an apparent conductivity of Earth formations.

[c25] The method of claim 20 wherein the digitally sampling is performed at a rate of at least about one thousand times a frequency of the current flowing from the first selected position so as to enable determination of transient effects.

[c26] The method of claim 20 wherein the conducting an electrical current between the first selected position and the fourth position, and the conducting electrical current between the first position and the fifth position comprises switching polarity of a direct current.

[c27] The method of claim 26 wherein a frequency of the switching is within a range of about 0.2 t0 20 Hertz.

[c28] The method of claim 26 wherein the switching is performed according to a pseudo random binary sequence.

[c29] The method of claim 20 wherein the conducting an electrical current between the first selected position and the fourth position, and the conducting electrical current between the first position and the fifth position comprises generating alternating current.

[c30] The method of claim 29 wherein a frequency of the alternating current is within a range of about 0.2 to 20 Hertz.

[c31] The method of claim 20 further comprising selecting an axial distance between the second and third positions in response to an expected resistivity of the Earth formations.

[c32] The method of claim 31 wherein the selecting an axial distance comprises generating an initial model of the Earth formations, estimating a resistivity of the Earth formations from the digitally sampled voltage measurements and selecting the axial distance based on differences between the initial model and the estimated resistivities.

[c33] The method of claim 20 further comprising selecting an axial distance between the first position and at least one of the second and third positions in response to an expected resistivity of the Earth formations.

[c34] The method of claim 33 wherein the selecting an axial distance comprises generating an initial model of the Earth formations, estimating a resistivity of the Earth formations from the digitally sampled voltage measurements and selecting the axial distance based on differences between the initial model and the estimated resistivities.

[c35] The method of claim 33 further comprising passing a focusing current through the pipe at selected axial positions, the axial positions for passing the focusing current selected in response to at least one of the initial model and the differences between the initial model and the estimated resistivities, the focusing current having a flow path selected to constrain the electrical current flowing from the first position substantially to a predetermined geometry.

[c36] The method of claim 35 further comprising adjusting a magnitude of the focusing current in response to at least one of the initial model and the differences between the initial model and the estimated resistivities.

[c37] The method of claim 35 further comprising measuring a voltage drop across selected monitoring positions along the pipe, and adjusting a magnitude of the focusing current so that the voltage drop across the selected monitoring positions is substantially zero.